PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in Condensing Surface Structures particularly for use in Distillation Apparatus

We, GENERAL ELECTRIC COMPANY, a Corporation organized and existing under the laws of the State of New York, United States of America, residing at 1 River Road, Schenectady 5, New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to condensing surface structures particularly for use in distillation apparatus and it has for one of its objects to effect certain improvements therein by which greatly increased amounts of heat transfer are obtained.

In certain classes of such apparatus, steam is applied to the surface of a heat conducting barrier to heat the barrier by reason of the latent heat of condensation flowing from the vapor into the barrier. By thus heating the surface, distilland applied to the opposite surface may be vaporized, the latent heat being transferred from the barrier to the vapor produced on the other, or output side. This vapor may then be condensed on the first-mentioned surface of the barrier as in compression distillation apparatus, or conveyed by conduit to a separate condensation surface as, for example, in molecular distillation apparatus.

The efficiency of such apparatus is dependent upon many factors which affect the transfer of heat from the vapor to the barrier on the input side, its transfer through the barrier, and its transfer from the barrier to the vapor on the output side. Since the barrier itself can be made of high heat conductive material, it may be disregarded and we may consider only the other two coefficients of heat transfer.

It may readily be shown that increase in either the coefficient of transfer of heat from vapor to the barrier on the input side, or that from the barrier to vapor on the output side, increases to some extent the total coefficient of transfer of heat from vapor on the input side to vapor on the output side.

It can also be shown that the heat transfer coefficient indicating vapor to vapor transfer of energy increases substantially more when both coefficients are increased simultaneously than would result if each coefficient were increased separately and the individual increases thus achieved were added together.

For example, let us assume a simple vapor barrier of cylindrical form having high heat conductivity and having vapor applied to the external surface for condensation thereon to heat the barrier and having distilland applied to the inner surface to be vaporized by the heated barrier. We may then let U equal the total overall heat transfer coefficient from the vapor on the outside of the cylinder to the vapor on the inside of the cylinder, and we may let h_1 be the heat transfer coefficient from the vapor on the outside of the cylinder to the barrier, and h_2 represent the heat transfer coefficient from the barrier to the vapor inside of the cylinder. Then we may write:

$$U = \frac{1}{\frac{1}{h_1} + \frac{1}{h_2}}$$

We may then consider several different situations as represented by the following table:

[1·

HEAT TRANSFER COEFFICIENTS

	Input side vapor to barrier	Output side barrier to vapor	Total Vapor to vapor	Percent Increase
Case 1	2,000	500	400	20%
Case 2	14,000	500	482	
Case 3	2,000	40,000	1,900	445%
Case 4	14,000	40,000	10,350	

In each case, the coefficient of heat transfer is to be considered the number of British thermal units (BTU) transmitted per square foot of area of the barrier per degree Fahrenheit across the medium through which heat is to be transferred; as, for example, from the vapor on the input side to the barrier and from the barrier to the vapor on the output side, the total heat transfer coefficient being the heat transferred from vapor on the input side to vapor on the output side. The total coefficient in the above table is computed from the other assumed quantities by use of the above equation.

Comparing Cases 1 and 2, in both of which the output heat transfer coefficient is 500, we see that an increase in the input heat transfer coefficient in the ratio of 1 to 7 produces only a 20% increase in the total heat transfer coefficient.

Comparing Cases 1 and 3, in both of which the input side coefficient is 2,000, an increase in the output side coefficient in the ratio of 1 to 80 increases the output coefficient by 375% over the quantity obtained in Case 1.

Now, comparing Cases 3 and 4, in both of which the output heat transfer coefficient is increased to 40,000, an increase of the input heat transfer coefficient in the ratio of 1 to 7 produces a still further increase in the total heat transfer coefficient of 445% over the quantity obtained in Case 3.

An object of the invention is to produce a vapor condensation barrier, having a total heat transfer coefficient from vapor on one side of the barrier to vapor on the other having a value comparable to that of Case 4.

The high coefficient of heat transfer on both sides of the barrier is obtained by designing the vapor condensing surface profile of the vapor barrier to maximize the condensation of vapor on it and the transfer of heat through it. This maximized heat transfer coefficient combined with the high output side heat transfer coefficient produced, for example, by the slipper bearing action of a wiper utilized for distributing the distilland over the barrier results in greatly increased heat flow through the barrier.

R. Gregorig, in an article published in "Zeitschrift fuer Angewandte Mathematik und Physik", Vol. 5, 1954, pages 36—49, describes a condensation surface which is undulated or fluted to increase condensation. In that structure the condensation surface is vertical and is undulated vertically. The undulations are of sine wave form and produce a very thin film with low heat transfer resistance at the summits of the protruding portions of the undulations. The condensate is drawn by surface tension from the summits into, and substantially filling, except for the effect of gravity, the grooves between the summits. In these grooves the condensate flows downward under the influence of gravity and drains away.

In accordance with the invention there is provided a condensing surface structure, particularly for use in distillation apparatus, made of good heat conductive material, one surface of which serves as an evaporation surface, the other surface being fluted or undulated vertically and serving as a vapor condensing surface and condensate runoff; liquid to be evaporated being distributed on said evaporation surface in form of a thin film, wherein the flutings or undulations are formed such that the valleys between crests serving as condensate runoff the unsymmetrical with respect to a line between the top of the crest and the bottom of the valley, such that the flutings form narrow grooves, the condensation area of each crest being larger than the valley runoff area, preferably at least twice as large, thereby effecting efficient heat transfer through the structure by combining a maximum condensing area substantially free of condensate with a minimum area for drainage.

Briefly, therefore, the invention provides a fluted condensing surface having outward projections and valleys therebetween so profiled and proportioned as to maximize the heat transfer coefficient from the vapor to the surface.

Effective use is thus made of surface tension in the film of condensate to drain off the condensate into narrow grooves while a thin

film of condensate having low heat transfer resistance is maintained over the broad crests on both sides of each groove.

In the accompanying drawings:

Fig. 1 represents a surface constructed in accord with this invention;

Fig. 2 shows a cross section thereof;

Fig. 3 is an enlarged cross section of a pair of adjacent protruding portions of adjacent undulations of the surface separated by a narrow drainage groove;

Fig. 4 shows, by way of example, an apparatus of the vapor condensation type having high heat transfer coefficients for both sides of the barrier;

Fig. 5 shows a detail thereof;

Fig. 1 shows a cylinder 1 of heat conducting material which may comprise, for example, the vapor barrier of a distillation apparatus. The inner cylindrical surface 2 is cooled to effect condensation of vapor on the outer surface. If this outer surface were plain, like the inner surface, the barrier would have its lowest heat transfer coefficient through it. Any grooving of the external surface increases this heat transfer. The external surface is provided with parallel vertical grooves or undulations having outwardly projecting crests 4 and inwardly projecting valleys 5. These broad crests provide a maximum area for condensation of vapor while the narrow grooves restrict the runoff to the minimum area necessary for channeling the runoff;

Fig. 3 shows, in a greatly enlarged way, two of these crests 4 and a valley 5 therebetween profiled and proportioned in accordance with the invention.

The condensation area on each crest extends not only over the summits, but also over the entire sides of the outward projections as well, a distance of twice the length w. Drainage is confined to the surface area of radius R between the bottoms of the crests, or outward projections, and extends over the relatively narrow range between one length w to the adjacent length w.

The term "crest" is intended to apply to the entire projecting portion of the undulation, having the width 2w as shown in Fig. 3, not merely the summit portion of the projection. In general, the crest is all of that portion projecting above the surface of condensate flowing in the drainage groove.

The surface profile required to produce maximum condensation may be calculated mathematically by considering the forces acting on the condensate film. It can be shown mathematically that the following relations exist:

w = half width of the crest of the undulation
x = distance from summit of crest, along arrow w
r = radius of curvature of crest at a distance x, from summit
r_0 = radius of curvature at summit of crest
μ = viscosity of condensate
T = Total thickness of the film in an incremental portion on the surface
H_L = latent heat of condensation
d = density of condensate
σ = surface tension of the condensate
k = heat transfer coefficient of the condensate
Δt = temperature difference between outer surface of the film being evaporated and the surface on which condensation takes place
L = Vertical length of surface
R_1 = total internal heat transfer resistance, including that of the wall between the evaporating and condensing surface
m = ratio of length of groove before it is full of condensed liquid, to total vertical length L.

Assumptions:

(1) Surface, on which profile is to be provided is cylindrical and of diameter which is large with respect to depth of undulations.

(2) Radius r is infinite, at distance x = w (or, angle B, Fig. 3, $=\pi/2$).

$$\frac{1}{r} = \frac{1}{r_0} - \frac{3\mu\,\Delta t K x^2}{2T^4 H_L \sigma d} \qquad (1)$$

or

$$\frac{1}{r} = \frac{1}{r_0} - Cx^2 \qquad (1a)$$

where C is a constant including all constants in equation (1). From these equations (1) and (1a) the profile of that portion on which filmwise condensation occurs may be constructed, i.e., the area of one half of the crest in Fig. 3. Further,

$$r_0 = \left(\frac{4}{3\pi}\right)^{2/3} C^{-1/3} \qquad (2)$$

This equation (2) determines the radius R of the semi-circular drainage groove and with equation (1) for the crest, the entire profile of the surface undulation is determined.

The maximum condensing areas can now be calculated. The following is obtained:

$$w^3 = \frac{3\pi}{4C}\,; \text{ or } \qquad w = \sqrt[3]{\frac{3\pi}{4C}} \qquad (3)$$

and r_0 is determined:

$$R = \sqrt[4]{\frac{16}{\pi} m \frac{\mu L_W \Delta t}{(R_1 + T/K) H_L d^2}} \qquad (4)$$

Thus, substituting (4) in (1a) and inverting:

$$T = \frac{1}{\sqrt[3]{\frac{C}{(4/3\pi)^2}} - Cx^2} \qquad (5)$$

To construct the profile, let it be assumed that water is the medium to be condensed on the surface and that condensation occurs at 49° C. Then the values for various constants are as follows:

μ, viscosity: .0055 dyne-seconds/sq. cm.
k, heat transfer coefficient:

$$.00154 \frac{\text{g. cal.}}{\text{cm. sec. deg. C.}}$$

H_L, latent heat of condensation: -570 cal./gram d, density: .99 gram/cubic cm.
σ, surface tension of condensate: 68 dynes/cm.

The tube profile shall be designed for a film thickness T of .00075 cm. for a difference in temperature Δt across the barrier of 2 degrees Centigrade and a ratio $m = 2/3$. Then applying equation (1):

$$\frac{1}{r} = \frac{1}{r^0} - \frac{3\,(55 \times 10^{-4})\,154810^{-5})\,x^2}{2\,(75 \times 10^{-5})\,4\,(570)\,(68)\,(.99)}$$

$$= \frac{1}{r_0} - 2100\,x^2$$

and $C = 2100$.

From equation (4):

$$r_0 = \left(\frac{4}{3\pi}\right)^{2/3} (2100)^{-1/3} = .044 \text{ cm.}$$

This is the radius of curvature at the summit of the crest.

From equation (3):

$$w = \left(\frac{3\pi}{4 \times 2100}\right)^{1/3} = .103 \text{ cm.}$$

This is the total distance from the summit of the crest to the extremity of the crest where it joins the drainage area.

From equation (5):

$$r = 1/(23.8 - 2100\,x^2) \qquad (6)$$

The radius r, for any point of the surface, at any distance x from the summit of the crest, may now be calculated from equation (6) above.

The values appearing below were obtained from equation (6) and the relation $\Delta x = r\Delta\beta$ (in radians).

	$r_0 = .044$ cm
$\Delta B_0 = 44°$	$r_1 = .051$ cm
$\Delta B_1 = 23.5$	$r_2 = .068$ cm
$\Delta B_2 = 17$	$r_3 = .147$ cm
$\Delta B_3 = 5.5$	$r_4 = .320$ cm

Fig. 3 is drawn roughly in proportion to these values showing the different radii r_0, r_1, r_2, r_3, and r_4 and the different corresponding angles $\Delta\beta_0$, $\Delta\beta_1$, $\Delta\beta_2$, and $\Delta\beta_3$. After the first radius r_0 and its corresponding angle $\Delta\beta_0$ is laid off on the drawing, the other radii and corresponding angles may be laid off on the drawing in succession.

It will be observed from Fig. 3, that the area to which drainage is confined, which is that area having the radius R, is substantially narrower than the condensation area, the latter being the entire balance of the area. All condensation on the length "w" at each side of the drainage area drains by reason of surface tension in the condensate film substantially horizontally toward the drainage area. With the configuration shown, the area on which condensation occurs is not only greater than the drainage area, but is substantially greater than the total surface area would be were it a plain cylindrical surface.

In a particular application, the highly efficient condensation surface between drainage areas was 144% of the total unprofiled surface, and by such profiling the heat transfer coefficient for filmwise condensation was increased from approximately 14640 kilocalories per hour per square meter per degree Centigrade to an actual realized amount in excess of three times that amount. Larger increases are possible, the realized gain in the actual construction having been reduced by inaccuracies when cutting the profile.

The invention, however, is not limited to the particular profile shown in Fig. 3, of which an example is computed herein.

As illustrated in the drawing, if we consider the general plane of the surface to extend through the center from which the radius R, defining the drainage area, is measured (or approximately on the line of radius r_4 as shown on the drawing), it will be found that the surface relation between the projecting portion and drainage portion of the undulations, is substantially three to one. Since the drainage area is covered by draining fluid, it contributes little to condensation, but it occupies only about one-quarter of the total surface as measured in the above referred to general plane. The projecting por-

tion occupies approximately three-quarters of the width of the undulating surface but only twice the size of the groove as measured along a line tangent to the bottom of the groove and parallel to the mine, evaporation surface. Thus, the area on which condensation occurs uninhibited by substantial drainage may be in the neighborhood of 144% of the overall width of the unprofiled surface.

Since the area 5 serves only for drainage purposes and does not substantially contribute to condensation, it may be of any desired shape, such as rectangular or other polygonal shape. Similarly, the projecting portions extending beyond the general plane through the base thereof referred to above may also be varied, but it will be found advantageous always to maintain a peripheral length of the area on which condensate occurs uninhibited by substantial drainage greater than the general overall width of the unprofiled surface. The height of the projection above the general plane will generally exceed the width of the drainage area in that plane, and its width will normally exceed twice the width of the drainage area in that plane.

In most applications, the depth of the drainage groove at distance R from its bottom will be not greater than one-half of the height of the crest at the same diameter of the barrier. The slope of the side walls of the crest varies from an angle of substantially 90 degrees, or one usually greater than 80 degrees, to the general plane of the surface to parallelism with that general plane at the summit and liquid flows to a depth that substantially inhibits condensation only in the bottom of the drainage groove defined by radius R, except, of course, in the lower one-third of the length of the surface where the draining liquid may exceed the depth R but not enough significantly to reduce condensation.

Fig. 4 shows in greater detail a compression distillation apparatus. This comprises a cylinder 1, having an outer surface undulated in accordance with the invention, which is employed as a vapor barrier. These undulations produce a high heat transfer coefficient from the surrounding vapor to the barrier. A high heat transfer coefficient from the barrier to the vapor within the cylinder is produced by use of wipers 17 which produce a very thin film of distilland on the inner surface of the barrier from which it evaporates due to heating of the barrier.

Distilland to be distilled, which may be sea water, is supplied to the equipment by conduit 12, which enters a distilland distributor 13 at the upper end of and within the cylinder 1. This distributor is mounted upon, and rotates with, a shaft 14, which extends along the axis of the cylinder, and which is rotated by means of a motor 15. It is provided with passages 16 through which distilland flows to the inner surface 2 of the cylinder, where it is distributed by wipers 17.

The shaft 14 carries wipers 17, better shown in Fig. 5, which are caused to bear against the inner surface 2 by means of springs 18, also better shown in Fig. 5. The distilland is supplied to the surface 2 directly in advance of these wipers 17, and it runs down the entire length of the cylinder in advance of the wipers. The wipers 17, which are constructed of carbon or plastic material having good wear qualities and which are wetted by the distilland, have surfaces 19 inclined to surface 2 by a small angle, and which engage the surface 2 to act as slipper bearings to distribute the distilland in a thin film over the entire surface 2, thickness of the film being determined by the pressure of the springs 18 and the width and angle of engagement of the surfaces 19. By proper construction of these members, the film of distilland may be sufficiently thin so that it extends from one wiper to the next, thereby to cover the entire surface but only with sufficient thickness to avoid dryness of the surface in advance of the next wiper. Such dryness is objectionable because it is likely to result in the deposit of solids upon the surface. Furthermore, the layer of distilland is so thin that it does not flow by gravity over the surface, but lies upon it with uniform thickness except for the effect of evaporation.

Vapor rising from the surface 2 passes upward through passages 20 in the distributor 13, is compressed by the compressor 10, and passed downward through openings 25 in an annular collar 26 between the cylinder 1 and an outer cylinder 27 where it condenses upon the outer undulating surface of the cylinder 1. The condensate is drawn by surface tension to the drainage grooves of the surface of cylinder 1, and flows downward in those grooves to the bottom of the cylinder and out through distillate conduit 28.

Any excess distilland which does not evaporate from the inner surface 2 flows down in a narrow concentrated stream in advance of the wipers and out through concentrate conduit 29.

It will be noted that the wipers 17 are segmented along the length of the cylinder, the various segments being alike and each segment being independently spring pressed against the cylinder. In this way the effective wiping of the surface is achieved irrespective of irregularities therein.

WHAT WE CLAIM IS:—

1. A condensing surface structure, particularly for use in distillation apparatus, made of good heat conductive material, one surface of which serves as an evaporation surface, the other surface being fluted or undulated vertically and serving as a vapor condensing surface and condensate runoff; liquid to be

evaporated being distributed on said evaporation surface in form of a thin film, wherein the flutings or undulations are formed such that the valleys between crests serving as condensate runoff, are unsymmetrical with respect to a line between the tip of the crest and the bottom of the valley such that the flutings form narrow grooves, the condensation area of each crest being larger than the valley runoff area, preferably at least twice as large, thereby effecting efficient heat transfer through the structure by combining a maximum condensing area substantially free of condensate with a minimum area for drainage.

2. A condensing surface structure according to Claim 1, characterized in that the surface is cylindrical, forming a closed, inner evaporation surface, and the flutings are on the outside of the cylinder.

3. A condensing surface structure according to Claim 1, characterized in that the flutings, or undulations, are formed to have a cross sectional outline which is, substantially, and preferably entirely, determined by the expression:

$$r = \frac{1}{\sqrt[3]{\frac{C}{(4/3\pi)^2} - Cx^2}}$$

where r, C, and x are as defined in the specification.

4. A condensing surface structure according to Claim 1, characterized in that the grooves of the flutings are formed to have a cross section which is substantially semicircular, and preferably, entirely, determined by the expressions:

$$R = \sqrt[4]{\frac{16}{\pi} m \frac{\mu L_W \Delta t}{(R_1 + 1/K) H_L d^2}}$$

where the values are as defined in the specification.

5. A condensing surface structure according to any of the preceding claims and in combination with means to supply liquid to be evaporated to the evaporation surface, and duct means to supply the vapor evaporated from the evaporation surface to the condensing surface.

6. A condensing surface structure according to Claim 5, characterized in that the means to supply liquid to be evaporated to the evaporating surface includes distribution means, such as wipers, for distributing the liquid on the evaporating surface in the form of a thin film.

7. A condensing surface structure substantially as shown and described and with reference to the accompanying drawings.

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Fig.1.

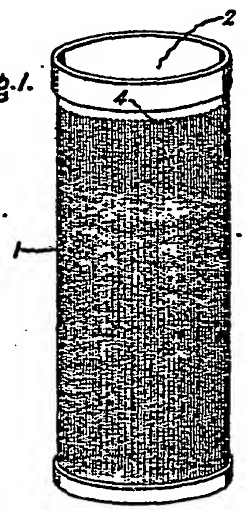


Fig.2.

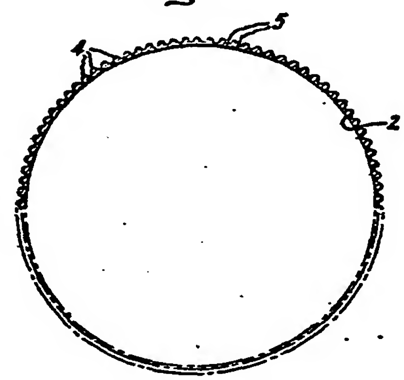
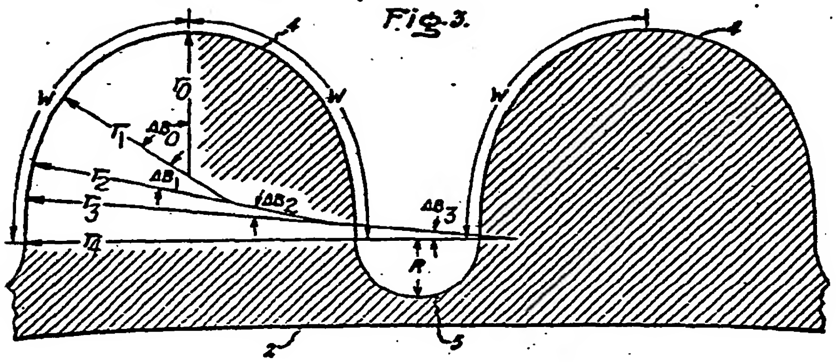


Fig.3.



889157 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1 & 2

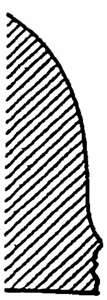


Fig. 4.

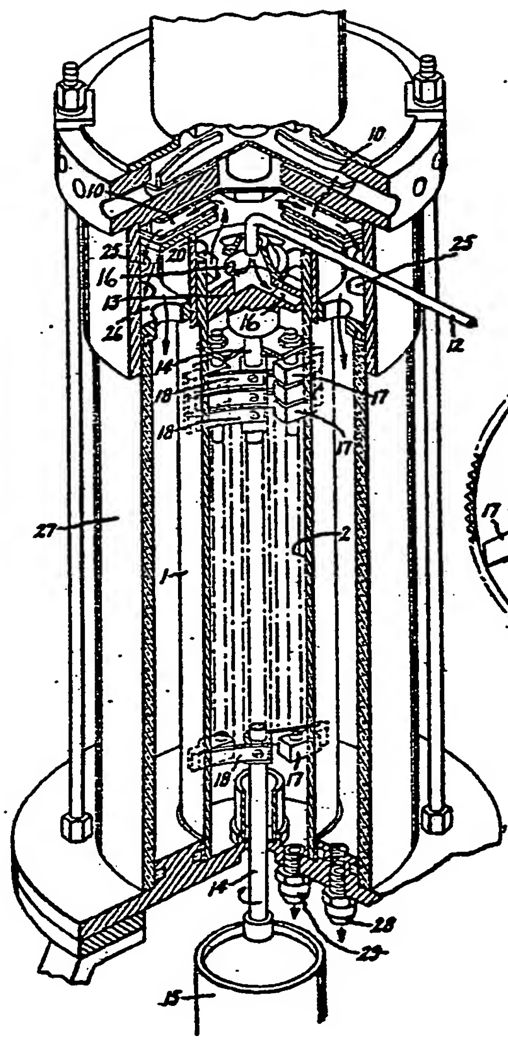
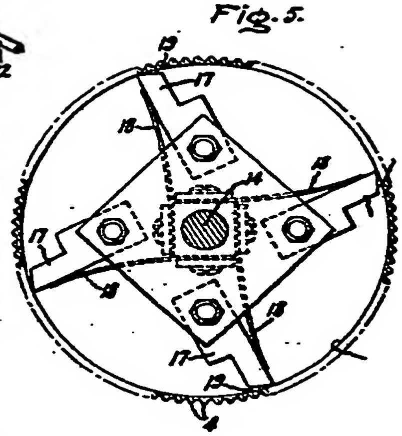


Fig. 5.



839157 COMPLETE SPECIFICATION

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Sheet 1 & 2

Fig. 1.

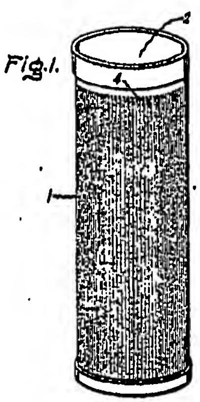

Fig. 2.

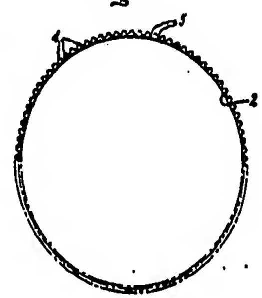

Fig. 3.

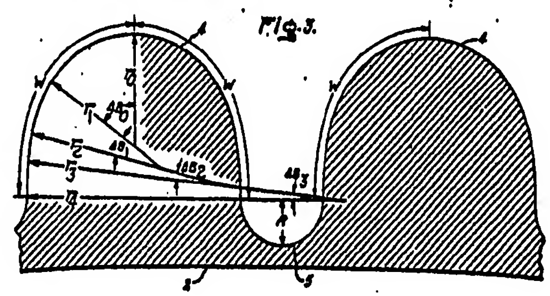

Fig. 4.

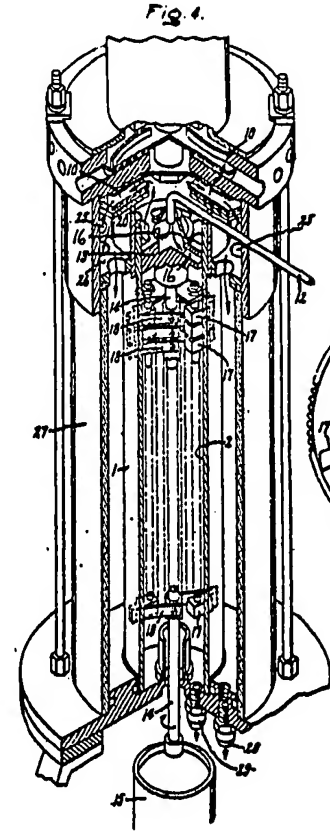

Fig. 5.